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Towards empowerment of the renewable energy sector in Pakistan for sustainable energy evolution: SWOT analysis

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ABSTRACT

The present study performs an analysis of the Strengths, Weaknesses, Opportunities, and Threats (SWOT) as a reference point that diagnoses the feasibility of current status and future roadmap to nurture the renewable energy sector in Pakistan. The results identify the social, economic and environmental impacts on the sustainable development of the renewable energy sector through explicit and categorical investigation of strengths, weaknesses, opportunities, and threats in local perspective. Hence, strengths of the renewable sector in terms of available renewable energy potential, validated resource maps, environment friendliness, and the growing private investors are explored, whereas inefficient technologies, huge capital investment, immature institutional framework, and technology-related environmental hazards are found to be the internal weaknesses that need to be fixed. Main opportunities that are found mandatory to be capitalized for the sustainable development are: untapped potential, micro and mini-installations, off-grid energy systems and efficiency improvements, whereas associated threats to be defended for the sustainability of the renewable energy sector are: policy implications, lack of grid connection, and the competitive energy resources. Furthermore, to cope with the energy crisis under the current scenario, policy-based strategies are suggested to ensure the retainability of the renewable energy sector towards secure and sustainable Pakistan.

1. Introduction

The investment level in projects relevant to Renewable energy has been increased drastically all around the globe in the last decade (2007–2017). It was observed to be $104 billion in 2007 which jumped to $279.8 billion in 2017. This dramatic increase doubled the installed renewable power generation capacity from 1070 GW (2007) to 2195 GW (2017), expanding to more than double. This trend is plausible to continue for sustainability vitalization and pollution free environment. Hence, various countries have entrenched challenging targets for upcoming years on the renewables power sector. Renewable energy sources (RES) are always coupled with variability and uncertain weather conditions that make it inevitable to devise a scheme or algorithm for their efficient integration with Power Systems. Hence, several research studies [1–4] have been published in recent years to serve the purpose. Ever-growing energy demand is another prime reason for any country to invest in a safe future. Worldwide energy consumption is expected to rise up to 28% between 2015 and 2040, whereas in Asia 51% increase in energy consumption is expected, largest in any other region in the world. Currently, more than 1.4 billion people have no electricity access, the majority of them belong to the Africa region. While in India 400 million people are directly affected whereas in Pakistan this figure is 25 million. In 2017 near about 6500 MW electricity deficit was observed in Pakistan [5].

In present time load shedding of up to 18 h a day is common practice in Pakistan that has to be faced by its people with even worsening conditions in rural-based areas. The exploitation of renewables like wind and solar would offer the best possible solution as by utilizing these sources effectively there is a lot of potential in Pakistan to meet its Energy requirements [6]. Identification of resources along with exploring the reasons behind the energy crisis in Pakistan, for remedial identification, may serve the purpose [7]. A roadmap is developed from Pakistan's perspective to fulfill energy requirements, also immediate steps to be taken by the government are highlighted for future needs. Furthermore, stakeholders are guided towards energy crisis-free future by pointing out some

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significant sources to be considered to resolve the issue [8]. Pakistan's current Energy mix ratio, supply and demand gap, availability of resources to meet future needs and various key dimensions have been presented briefly with the aim to not only overcome the severe energy crisis but also to achieve a greener environment in Pakistan [9,10]. Another study analyzed various possible renewable based scenarios in Pakistan to explore the best one for secure energy supply in the future [11]. Pakistan's current and future renewable energy mix is presented concisely [12]. A quantitative and analytical study is conducted to abridge the supply and demand gap using TIMES model [13].

To highlight the significance of staunch financial and political commitment towards a vigorous policy a cross-country comparative analysis of successful policies, that led to renewable implementation, is executed [14]. Furthermore, optimum scenarios are given for energy productivity through linear programming model in available resources of Pakistan. In addition, challenges for the energy sector and major policy elements to tackle these challenges is provided [15].

Some possible smart grid applications in Pakistan have been presented by utilizing the best available resources and wireless technologies. It may help to integrate organizations and national grids. Also, some techniques have been discussed to implement smart grids in this country [16]. A study is presented for a prosperous future of Pakistan, key findings and suggestions are: the significance of microgrid establishment in industries is inevitable to save energy, a way to reduce power outages, roadmap for enhanced mechanical efficiency, how to improve socio-economic infirmity and electrification [17].

This paper tries to retort the following questions. What are the strengths of the renewable energy sectors in Pakistan? What weaknesses may hinder the progress of the renewable energy sector? What opportunities are available to promote the renewable energy sector? What are the threats that may degrade the performance of the renewable energy sector?

The organizational structure of the study is as follows: section 2 presents the SWOT analysis and its global progression for the renewable energy. Section 3 discusses the methodology adopted while performing a SWOT analysis. Section 4 presents the results and findings of the SWOT analysis of each renewable energy source and, section 5 concludes the study with policy-based recommendations.

2. SWOT analysis and its global progression for renewable energy

A SWOT analysis derived from its initials is well-structured strategic planning to assess the current status of the business in the market by evaluating its strengths (S), weaknesses (W), opportunities (O), and threats (T) [18].

It is based upon internal and external evaluation criteria. The internal analysis is performed to interpret and highlight the strengths and weaknesses of any organization or any sort of strategic planning, whereas external analysis is conducted to explore the associated opportunities and threats present in the market. It was primarily developed for marketing analysis and business analysis purpose afterward widely adopted in many other fields for research assistance including energy sector [19].

Strengths and weaknesses are the internal indicators of a business while the opportunities and the threats are the external indicators. Strengths are the factors that may enhance the overall performance, whilst weaknesses may affect the efficiency, profitability and competitive advantage. Opportunities are possibilities that may add to progress and threats are the issues that may generate problems [20]. The scheme of the SWOT analysis is shown in Fig. 1.

Strengths and the opportunities are the positive attributes in achieving the objectives, providing an advantage over others, and the likelihoods to exploit the advantage from the available opportunities respectively; while the weakness and the threats are the negative attributes. The positive internal indicator is the asset of the business that is used to eliminate the negative external indicator; the positive external indicator is used to overcome the negative internal indicator. The contribution of the SWOT analysis for the sustainable development of the renewable energy sector is to maintain the strengths, fixing the weaknesses, capitalizing on the opportunities and defending against the threats.

SWOT analysis is extensively adopted by researchers for energy planning. In this regard, a detailed study of Association of Southeast Asian Nations (ASEAN) is presented through SWOT analysis to explore the possibilities and associated complications towards greener energy mix for future of ASEAN region [21]. Another comprehensive review of East Asian countries including Japan, South Korea, and Taiwan, performs SWOT analysis in the context of possible technological advancements as well as the potential of exporting the green energy [22]. A study is conducted for a PV system installation on buildings in the Gulf Cooperation Council (GCC) countries by applying SWOT analysis. Various technical and nontechnical factors are considered [23]. A research undertakes Hebei Province of China as a test case to apply SWOT analysis for sustainable energy deployment in the industry [24]. Another SWOT–AHP–TOWS based study encourages private investors to support biogas investment in China. SWOT analysis is performed to recognize stakeholders, analytical hierarchy process (AHP) sets priority and TOWS matrix explores strategic approach [25]. SWOT analysis is performed to develop a solid strategy for China's renewable resources based industries and then most suitable approaches are suggested in current context [26,27]. Towards advanced energy planning in Turkey, SWOT analysis along with Analytical Network Process (ANP) and fuzzy logic based technique TOPSIS is applied to investigate the factors for prioritization of alternatives for locally accessible energy strategies [28]. In 2015, renewable contribution in Cyprus for overall energy mix was 8.5% and is projected to be 44% in 2044. Hence SWOT analysis is used to exploit feasible opportunities and possible barriers with solutions towards sustainable future [29]. An extensive study explores the work done in past, current research work and future based SWOT analysis of Wind sector in Poland. Moreover, some plausible solutions and their fringe benefits have been presented to enhance wind energy based renewable contribution [30]. SWOT analysis-based study is conducted to examine the effectiveness of energy in Ukraine from the economical viewpoint. Each factor involved in

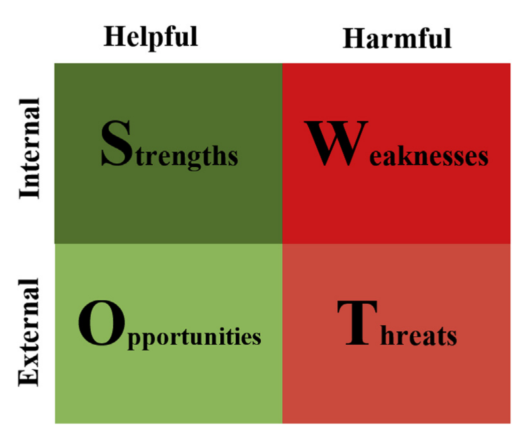

Fig. 1. SWOT analysis scheme.

SWOT analysis is explicitly described [31]. To attract the investors to spend on Renewable based Energy Systems in Tunisia, SWOT analysis is used to conclude the prime factors and principle steps to be taken immediately [32]. All stakeholders in Jordan are contributing to reaching the 10% mark of injecting renewable into the Overall Energy mix. Hence basic strategy, current energy mix, potential resources, probable impediments and necessary actions against them are discussed briefly in Ref. [33].

This robust and extremely effective technique is found to be very helpful to clearly point out the current flaws and providing future direction. As in 2014, SWOT analysis was applied to explore wind power sector in Poland [34] and a remarkable improvement was found later on. Since Pakistan is under the immense pressure of energy dearth although there is no scarcity of resources. Tremendous possible resources are yet unexplored and/or unutilized due to lack of awareness and imperfect government policies. So, SWOT analysis in the context of Pakistan's renewable energy sector is not performed yet. We believe that our initiative will assist the stakeholders towards filling the energy Sum in Pakistan by exploring the best potential resources and/or alternatives on a priority basis.

3. Methodology

SWOT analysis even well-organized may become onerous in terms of concordant decisions. Therefore, it becomes ineludible to use comprehensive as well as precise data to avoid any ambiguity. Hence a broader definition of internal and external factors is required in terms of the sector to be explored prior to SWOT analysis [35]. Following the streamline, renewable energy resources in Pakistan need to be explored on a large scale. Renewable Energy data extensively need to be collected and recorded but we must originate internal and external factors explicitly, to begin with. Elucidation approach of the SWOT analysis is explained in Fig. 2.

While conducting a SWOT analysis, the authors addressed the following queries regarding the internal and external parameters (strengths, weaknesses, opportunities, and threats). The SWOT analysis of the renewable energy sector of Pakistan was accompanied by answering the following questions through the detailed survey of the working papers, national energy reports and statistics, newspaper articles, academics journals [36], TV news, reports, books, unstructured interviews, and the electronic materials.

- Are the ordinary conditions of the region in favor of the development of RE sources?
- What are the interests of investors, developers, and promoters in RE projects?
- What is the knowledge level of locals regarding RE sources?
- What are the subsidies and profits available in RE projects?
- Has the RE achieved grid parity or is it cheaper than fossil fuel-based electricity?
- What is the level of cooperation between federal and provincial governments?
- Is there a win-win strategy among different institutions of the State?
- What is the level of coordination between energy and climate policies?
- What is the impact of RE and fossil fuels on the environment?
- What is the demand for electricity in that region?
- Is there anyone window facilitator in organizing and licensing the projects?
- Which best technology is available and what is the level of knowledge of experts?
- What are the return rates and how much electricity is theft?
- How far is the grid from the newly recommended project site?
- What is the security for the availability of RE resources?
- Will the introduction of RE sources create new jobs?
- Is there any opportunity for technology development at the mini and micro scale?
- What are the economic growth opportunities for the development of RE-based projects?
- Is the current energy policy support the promotion of the RE sources?
- Will the local laboratory research improve the efficiency and mitigate the electricity prices from RE sources?
- What is the level of accuracy of the available metrological data (wind, solar, biomass)?

4. Results and discussion: SWOT analysis

4.1. Wind energy

4.1.1. Strengths

4.1.1.1. Resource potential. The major among the strengths of the Wind energy in Pakistan is the potential that is profusely available in the country especially in Sindh and Baluchistan coastal belt (Fig. 3) with an average wind speed 7 m/s at 50 m anemometer height [8]. The potential sites along the 9700 km^2 coastal stormier areas in Sindh are Jamshoro, Mirpur Sakro, Keti-Bandar, Thatta, Shah Bandar, Gharo, Nooriabad, Kotri, Thar, Hyderabad, and Matli. However, in Baluchistan, Gawadar, Ormara, Chowki, Pasni, Liari, Gadani, Jiwani, and Hub are the best sites of wind potential. The determined wind potential of the coastal belt of Pakistan is 43 GW while as a consequence of the land utilization restrictions, only 11 GW is commercially exploitable potential [37,38]. According to the National Renewable Energy Laboratory (NREL), Pakistan has 346 GW wind energy potential for electricity production [8]. Table 1 details the wind energy potential of various qualities based on the wind class.

4.1.1.2. Highly accurate wind maps. The availability of meteorological maps is the surplus strength of the wind energy as the wind measurement data is easily available to the investors, developers, and the policymakers. To obtain the validated wind, biomass and solar maps of Pakistan, the World Bank's Energy Sector Management Assistance Program (ESMAP) is funding the ground-based solar and wind data assessment project in Pakistan. In its preliminary phase 1, the World Bank has issued a wind map (Fig. 3) of 13 years (2000–2012) using multiyear mean satellite and ground-based data [39]. For phase 2, 12 sites have been identified and wind mast of 80 m height has been installed to collect the wind data throughout the country. Once the two-year data is obtained, the World Bank will issue highly accurate and validated wind maps that would be available for the commercial and government wind energy developers [40].

4.1.1.3. Environment friendly-emission free. The greenhouse gas (GHG) emissions from wind power are 8–20 g per kWh which is only 2.2% of the emissions generated by the coal [41,42]. The GHG emissions from each energy source are summarized in Fig. 7.

4.1.1.4. Institutional framework and wind projects. Strengths of wind energy also include the increasing interest of private investors and the strong institutional framework. In Pakistan all the RE projects are carried out under Alternative Energy Development Board (AEDB) which had played its role well as a one window facilitator and now 6 wind power projects with a cumulative capacity of 308 MW have achieved their commercial operation date and are operational in Gharo-Keti Bandar wind corridor, Sindh

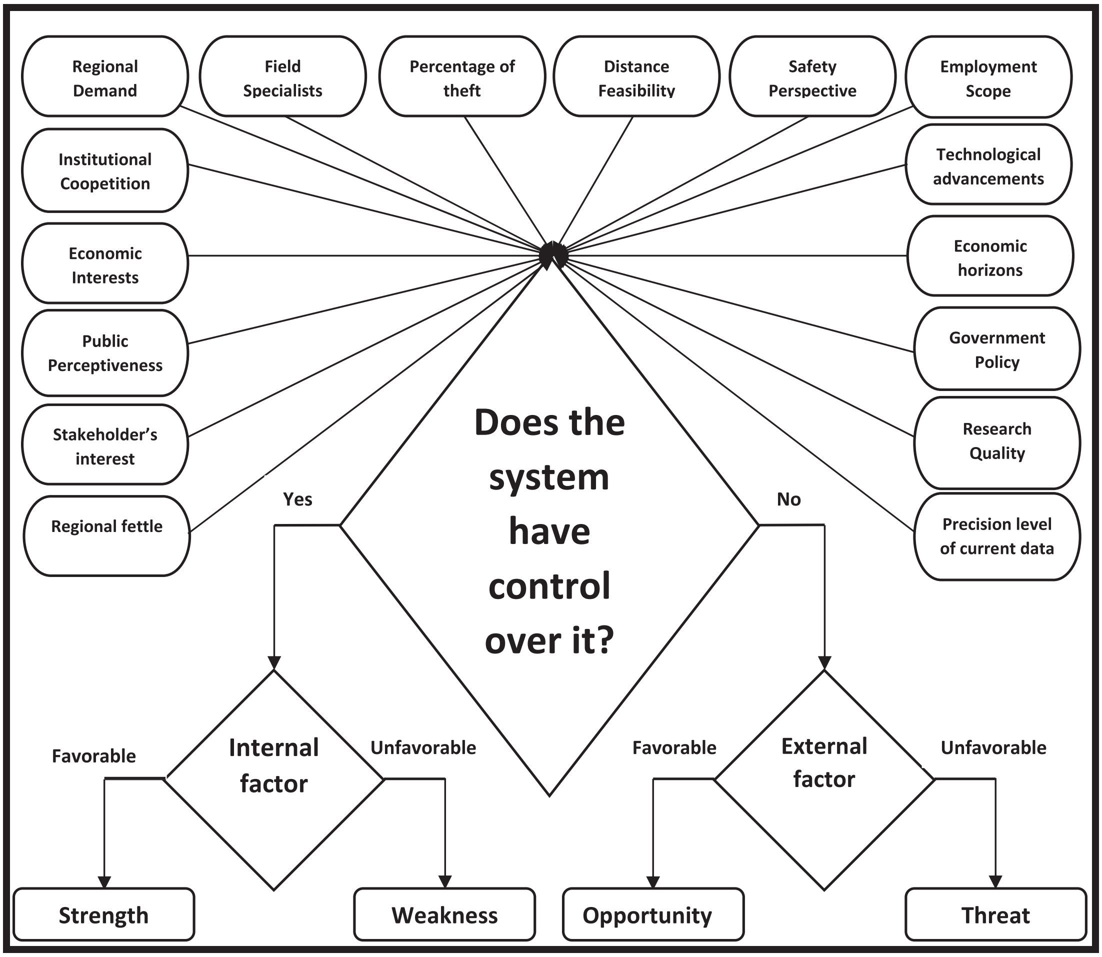

Fig. 2. Elucidation approach.

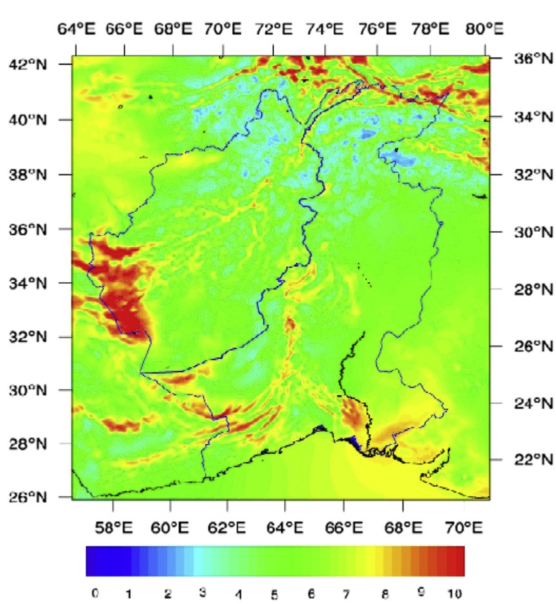

Fig. 3. Multiyear mean (2001–2010) Wind speed map at 100 m from the ground. (The color scale indicates wind speed in m/s). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

(Table 2); 9 wind power projects of cumulative capacity 477 MW are under construction while 14 projects of cumulative capacity 663 MW are in pipeline and expected to be operational until the first quarter of 2019. All the operational, under construction and in pipeline projects are in Gharo-Keti Bandar wind corridor.

4.1.2. *Weaknesses*

4.1.2.1. High initial investment. The weakness of high capital investment cost on wind farms is considered to be a big obstacle in the development of wind energy. Various authors envisage a reduction in LCOE of wind energy if the cost of the Balance of System (BOS) like a wind turbine, foundation, installation, grid connection, and project development and management costs are individually controlled and reduced. The most significant one is the cost of wind turbines as it is not developed locally and carries the cost ranging from 64% to 85% of the capital investment.

4.1.2.2. Environmental hazards. Regarding the environmental concern, wind turbines are relatively less dangerous to the environment than the fossil-fueled power plants. However, birds' mortality, the noise, and visual effects are some of the issues caused by the wind turbines. Hundreds of thousands of birds are killed by the wind turbine blades every year which is a direct threat to the existence of various birds species [44].

Another weakness of wind energy exploration is the noise pollution of the wind turbine. A wind turbine's noise is from two sources: one from the gearbox and generator and other from the

Table 1
Wind resource at 50 m height in Pakistan [37].

Wind class	Quality scale	Speed (m/s)	Power (kW/m^2)	Capacity (GW)	Area (km^2)
4	Good	6.9–7.4	0.4–0.5	90.53	18,106
5	Very good	7.4–7.8	0.5–0.6	26.09	5218
6	Excellent	7.8–8.6	0.6–0.8	12.48	2495
7	excellent	>8.6	>0.8	2.72	543
Total				**131.8**	**26,362**

Table 2
Operational wind power projects in Pakistan [12,43].

Name	Capacity (MW)	COD	Location
Fauji Fertilizer Company Energy Limited	49.50	May 16, 2013	Jhimpir, Sindh
Zorlu Enerji Pakistan (Pvt.) Limited	56.40	July 26, 2013	Jhimpir, Sindh
Three Gorges Pakistan First Wind Farm (Pvt.) Limited	49.5	November 25, 2014	Jhimpir, Sindh
Foundation Wind Energy II (Pvt.) Limited	50	December 10, 2014	Gharo, Sindh
Foundation Wind Energy –I Limited	50	April 11, 2015	Gharo, Sindh
Sapphire Wind Power Company Limited	52.80	November 21, 2015	Jhimpir, Sindh
Sachal Wind Farm	50	April 11, 2017	Jhimpir, Thatta
UEP Wind Farm	100	June 16, 2017	Jhimpir, Thatta
Hydro China Dawood Wind Farm	50	April 5, 2017	Gharo, Thatta
Total capacity	**508.2**		

aerodynamics. The aerodynamic sound is the dominant one which can be overcome by designing efficient aerodynamic blades of the wind turbine. Environmental Impact Assessment (EIA) report of the proposed 100 MW wind farm NBT-SZABIST in Gharo-Keti Bandar stated that the sound level in living areas will be within acceptable limits of the World Bank and Federal EPA. The farm is 1.5 km from the residential area.

4.1.2.3. Improper potential exploitation. Moreover, Wind energy potential is abundantly available in Sindh and Baluchistan (Fig. 3). The potential from Sindh's wind corridor is properly being tapped while neither a single project is operational nor in the pipeline in Baluchistan (Fig. 6).

4.1.3. Opportunities

4.1.3.1. Local efficient technology. Wind market in Pakistan is still under development. The market can exploit maximum wind potential by using efficient wind turbines with better aerodynamics. By using mini and micro wind turbines, off-grid wind energy system can be best of its kind in harnessing wind energy for far-off areas. PCRET has installed 155 small wind turbines of capacity 161 kW [45]. Locally developed efficient micro wind turbines would be handy in promoting micro and mini wind energy systems in Pakistan.

4.1.3.2. China Pakistan economic corridor. China Pakistan Economic Corridor (CPEC) is an additional opportunity to develop and promote wind energy in the country. CPEC is internationally considered to be a secure project and a milestone for the regional progress. So, investors are willing to invest in various energy projects. The government should conduct radical efforts in pursuing the investors to the RE projects in CPEC. The wind power projects at various stages of project development under CPEC are given in Table 3.

4.1.4. Threats

4.1.4.1. Improper site selections. The major threat to wind power plants is the sudden change in wind velocity and direction at small scales. Shear winds are a state mainly caused by the geography of the surrounding landscape, places near mountain elevations, or the proximity of buildings, highway flyovers, and other landmarks. A shear wind causes entering wind to flow vertically up the appearance of the turbines, on top of the normal wind going through the blade arc. The blades are loaded nonlinearly, sending fluctuating loads going over the drivetrain.

4.1.4.2. Lack of grid connection. The wind potential is mostly available at the seashore, mountain ranges, and coastal areas where the extension of the grid is a must. The grid extension to transmit the electricity from the wind farm to the point of use put the extra cost to the wind energy. Table 4 summarizes the SWOT analysis of wind energy in Pakistan.

4.2. Solar energy

4.2.1. Strengths

4.2.1.1. Resource potential. Pakistan lies in a region of high solar insolation receiving 5–7 kW h/m^2/day on the average in its 95% terrestrial [46]. Mostly, the deserted areas of Baluchistan, Sindh, and Punjab have the potential development in solar energy. It is estimated that only in Baluchistan, the sun shines on the average for 8.5 h/day giving 20 MJ/m^2 solar irradiance daily [47]. The total estimated solar potential in Pakistan by the National Renewable energy Laboratory (NREL), USA in cooperation with USAID is 2.9 TW [48,49]. This potential of solar energy would guarantee energy security and mitigate energy import dependency.

4.2.1.2. Highly validated and accurate solar maps. World Bank's Energy Sector Management Program (ESMAP) in collaboration with AEDB, launched a measurement campaign for ground-based solar data. The campaign worked in the following three phases and prepared highly accurate solar maps for Pakistan.

- **Phase 1**: In its preliminary resource assessment efforts, satellite-based data was collected and arranged for the solar resource potential assessment in Pakistan by preparing satellite-based solar maps. Fig. 4 shows the multi-year mean (2000–2012) data for DNI and GHI in kWh/m^2 verifying the availability of huge solar potential in Pakistan, especially in Baluchistan, Sindh and partially in Punjab.
- **Phase 2**: Installation of the solar measurement stations at the nine locations of the country, measuring the 2-year ground-

Table 3
Wind power projects under CPEC [43].

Name	Capacity (MW)	Status	Location
Western Energy (Pvt.) Limited	50	In pipeline	Jhimpir, Sindh
Three Gorges Pakistan-II Wind Farm (Pvt.) Limited	50	LOS issued in August 2016. EPA initialed on 30th Nov 2016. Construction activity started from equity. Financial Close March 2017. COD September 2018.	Jhimpir, Thatta
Three Gorges Pakistan-III Wind Farm (Pvt.) Limited	50	LOS issued in August 2016. EPA initialed on 30th Nov 2016. Construction activity started from equity. Financial Close March 2017. COD September 2018.	Gharo, Thatta
Sachal Wind Farm	50	COD achieved on April 11, 2017	Jhimpir, Thatta
UEP Wind Farm	100	COD achieved on June 16, 2017	Jhimpir, Thatta
Hydro China Dawood Wind Farm	50	COD achieved on April 5, 2017	Gharo, Thatta

Table 4
SWOT analysis of the wind energy in Pakistan.

Strengths 1) Viable wind potential. 2) Authentic and validated wind maps. 3) Gharo- Keti Bandar wind corridor. 4) Increasing private investors. 5) Reduction in GHG emissions. 6) Strong institutional framework.	**Weaknesses** 1) High capital cost 2) Noise pollution 3) Ignorance of the most potential province like Baluchistan.
Opportunities 1) Developing wind technology and increasing efficiency. 2) Development of small-scale off-grid installations. 3) China Pakistan Economic Corridor.	**Threats** 1) Wind shear and turbulence by the improper site selection of the wind plant. 2) Environmental concerns. 3) Lack of grid connection.
Recommendations 1) Development of competition in local windmill market. 2) Adoption of international standards in designing windmills. 3) Uniformly invest in RE projects in all provinces of Pakistan. 4) One window facility for investors. 5) Careful selection of wind farm location.	

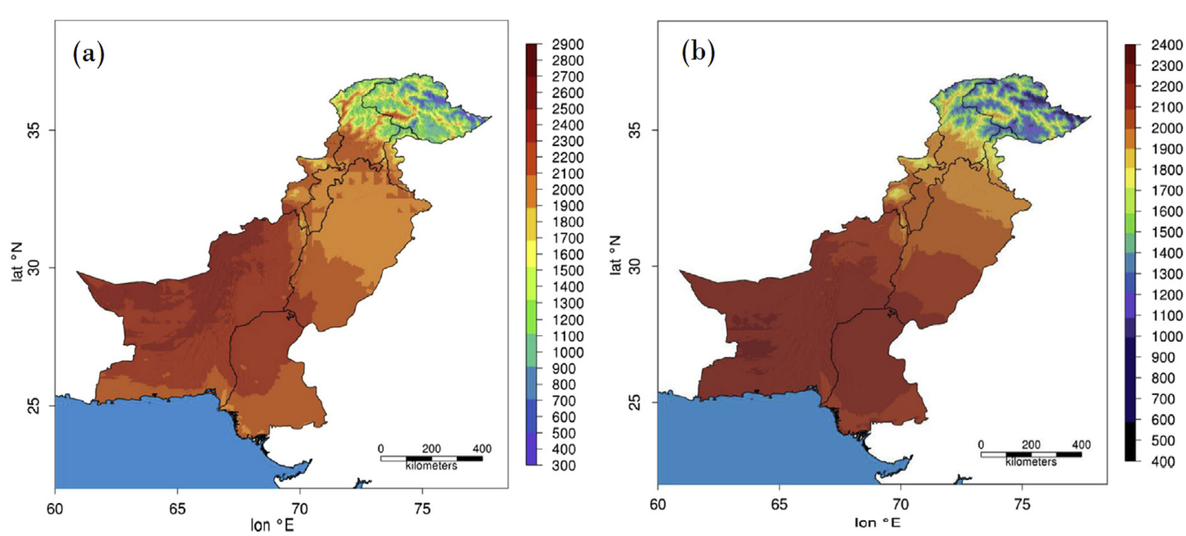

Fig. 4. Multi-year mean (2000–2012) of satellite-based (a) annual Direct Normal Irradiance (DNI in kWh/m^2), (b) annual Global Horizontal Irradiance (GHI in kWh/m^2) [59].

based solar data, and transmitting an average of daily solar radiations in 10 min intervals to validate and improve the already available maps.

- **Phase 3**: Preparation of the solar maps based on the ground measured data in phase 2. The latest solar maps based on ground measurements improved the accuracy of the solar maps of Pakistan. The uncertainty in the originally available GHI maps was ±6% to ±8% that after site model adaptation has been reduced to ±4% to ±6%. Whereas, the uncertainty in DNI maps has been decreased from (±10% to ±16%) in original maps to (±6% to ±14%) in the site adaptation model (Fig. 5).

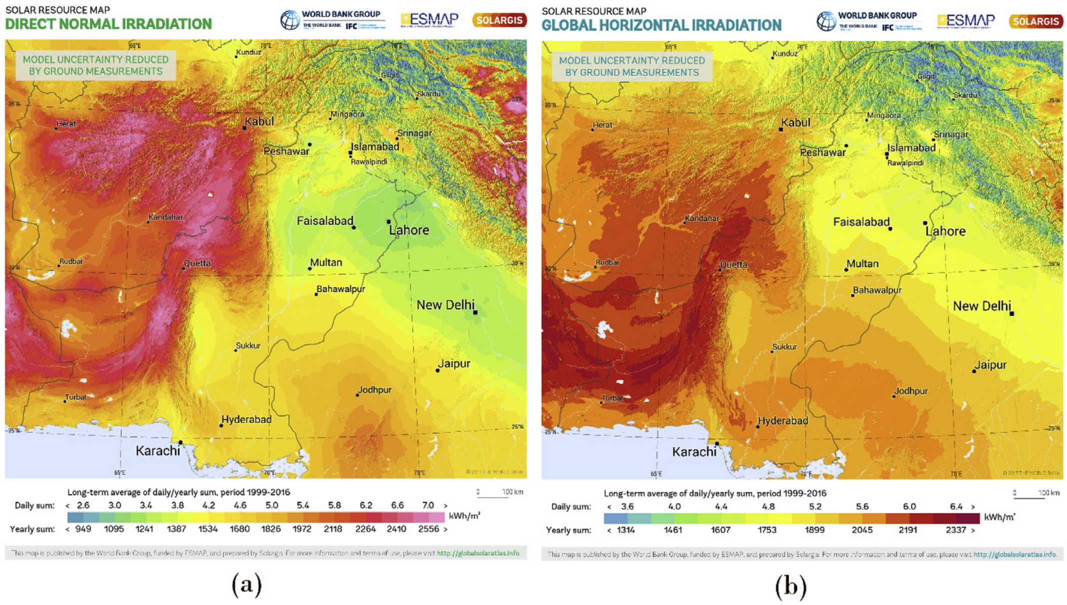

Fig. 5. Average daily/yearly (1999–2016) (a) Direct Normal Irradiance (DNI in kWh/m^2), (b) Global Horizontal Irradiance (GHI in kWh/m^2) for Pakistan calculated by Solargis model from atmospheric and satellite data [60].

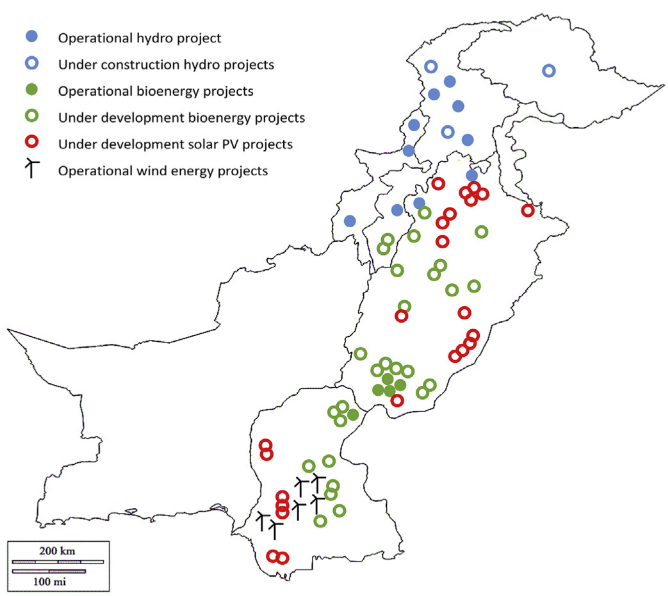

Fig. 6. Map of operational and ongoing RE projects in Pakistan.
(Source: Own figure, Data from AEDB, WAPDA)

4.2.1.3. *Increasing private investors.* Though till now, not a single grid-connected solar power plant is operational in Pakistan as shown in Fig. 6; almost 24 intended solar power projects of cumulative capacity 556 MW are under different stages of project development and expected to achieve commercial operation date in December 2018 (Fig. 6). With various public awareness strategies mostly in rural areas, solar PV is getting public acceptance and people have a proclivity to pay for the standalone solar home energy systems [50] either for their full load entertainment or for the partial load requirements.

4.2.1.4. *Environment-friendly.* Among RE resources, solar energy has the highest GHG emissions ranging from 26 to 217 gCO_2eq [51].

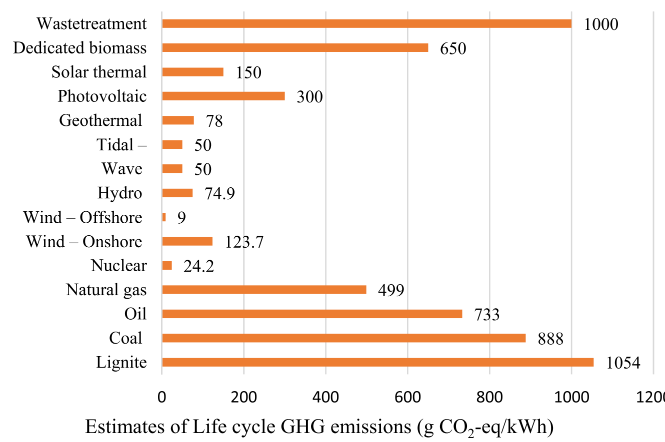

Fig. 7. Maximum GHG emission levels of electricity generation methods [51].

However, this value is much lowered as compared to the non-renewable energy resources (Fig. 7). In 2011, CO_2 emissions were 442 g/kWh which can be reduced to 212 g/kWh-331 g/kWh by adopting renewable energy [52].

4.2.1.5. *Minimum O&M.* In solar PV systems, O&M cost occurs because of the replacement of inverters and the scheduled cleaning of the PV modules. The inverters are warranted for 10 years and the cleaning and other maintenance are done twice a year. As the solar PV energy systems contain no rotary parts, so it requires no major Operation and Maintenance (O&M). No well-trained personnel is needed to operate the plant and the system incurs no major O&M cost. Most of the researchers assume the operation and maintenance cost about 1% of the capital cost [53].

4.2.2. *Weaknesses*

4.2.2.1. *Capital investment.* The major obstruction in the way of solar acceptance in the RE sector is the high investment cost. While installing a solar energy system, along with the PV modules, the balance of systems (BOS) like solar inverters, supporting structure, wiring, and ground purchases share a major cost of the whole solar energy system. These expensive BOS are causing a rise in the cost/W from the solar energy system.

4.2.2.2. Lack of DC appliances. For the sustainable development of the solar energy market, solar operated DC appliances need to be developed accordingly. If efficient DC appliances are developed and made available at cheaper rates, public acceptance will rise toward the use of solar energy.

4.2.3. Opportunities

4.2.3.1. Grid parity achievement. In various PV markets of the world, PV module prices are decreasing rapidly to such an extent that some of them had already achieved solar grid parity i.e. the price of electricity from solar PV is equal to or lower than the conventional fossil fuel-based electricity [54]. The opportunity of achieving grid parity also lies in the mitigation of the cost of solar supportive components like solar inverters, cables, installation cost, and the wiring [55].

4.2.3.2. Increasing efficiency of PV materials. With the increase in efficiency of the PV materials, the cost of the PV modules is rapidly decreasing. In Pakistan, by using more efficient materials, this opportunity of providing electricity from solar at grid parity is exploitable as the fossil fuel electricity is already extravagant. Once the grid parity is achieved, the people will prefer to use their own off-grid solar home energy systems.

4.2.3.3. Indoor Photovoltaic System. The elimination of the vulnerability of the PV module to the varying temperature is a major opportunity for the solar PV system. Hifsa et al. [56,57] proposed an optical temperature controller for the Indoor Photovoltaic System (IPVS) that filters out the infrared and ultraviolet radiations and allows only the visible portion of the solar spectrum to pass through. The proposed IPVS was tested in Pakistan's atmospheric conditions that if industrialized would be a breakthrough.

4.2.4. Threats

4.2.4.1. Conventional matured technologies. There are always some threats present to the organization, technology in this case. Conventional fossil fuel-based power plants are producing electricity at very cheap rates. These are the matured technologies having huge experienced experts, operators and technical personnel that could hinder the development of the solar energy in Pakistan.

4.2.4.2. Lack of incentives for micro/mini installations. In contradiction of the incentives for the grid-connected solar power plants, off-grid micro, and mini rooftop and ground-mounted PV installations are getting no incentives from the government like investment tax credit and feed-in tariff. If the government provides some lucrative subsidies and incentives to the micro and mini home energy system, solar PV installation will exponentially rise diversifying the energy mix.

4.2.4.3. Lack of balance of systems. An additional threat to the development of solar energy in Pakistan is the lack of supportive products like solar inverters and efficient DC home appliances [58]. Has estimated the savage of energy if DC appliances are operated on direct DC electricity from solar PV systems. These threats can be defended by importing energy star DC appliances and developing local DC appliances according to the availability and consumption of the energy. Summary of the SWOT analysis of solar energy in Pakistan is given in Table 5.

4.3. Bioenergy

4.3.1. Strengths

4.3.1.1. Resource potential and validated biomass atlas. Pakistan being an agrarian country have a huge potential of biomass production like wheat straw, cotton stalks and shells, corn cubs, sugar cane tops and trashes, bagasse, rice husk, animal dung, and poultry manure. Pakistan is the fourth largest producer of sugar from sugar cane generating bagasse for the electricity production. These biomass resources are locally available throughout the country and are used inefficiently for heating and cooking purposes. If properly exploited with efficient technologies, could be a source of rural electrification and biogas for cooking facilities. Uddin et al. [62] state that Pakistan has daily biogas potential of 12–16 million m^3 whereas Naqvi et al. [63] presented a detailed review of the biomass potential for bioenergy in Pakistan and declared the biomass of significant importance in future for electricity production.

AEDB successfully implemented a renewable energy resource mapping project to determine the quality and quantity of the biomass and the crop residue in Pakistan. The World Bank funded the project under its Energy Sector Management Assistance Program (ESMAP). The assessment program was carried out in the following three phases [64].

Table 5
SWOT analysis of the solar energy in Pakistan.

Strengths 1) Viable solar potential 2) Highly accurate solar maps. 3) Minimum O&M cost 4) Reduction in GHG emissions. 5) Highly public acceptance	**Weaknesses** 1) High capital investment. 2) Lack of efficient solar DC appliances. 3) Intermittency of solar irradiance in summer and winter.
Opportunities 1) Achievement of grid parity 2) Increasing efficiency 3) Development of solar home energy systems. 4) Indoor photovoltaic system 5) Socio-economic acceptance [61]	**Threats** 1) Availability of conventional matured technologies. 2) No incentives to micro and mini installations. 3) Lack of efficient solar related products (DC appliances, inverters, batteries, etc.).
Recommendations 1) Increase subsidies and incentives for each level of installation. 2) Development of DC home appliances. 3) Promotion of solar energy. 4) Educating people. 5) One window facility for investors.	

- Phase 1: project commencement, team building, identification and assessment of existing biomass data, and execution planning.
- Phase 2: field survey, collection, and analysis of data, and drafting of biomass maps.
- Phase 3: Creation and publication of corroborated biomass atlas for Pakistan.

The project was started in 2013 and completed in 2016. Raw survey data, atlas datasets and the maps were included in the final version of the atlas. Theoretical and the technical potential of the crop residue of wheat, maize, rice, cotton, and sugarcane were categorized as the harvesting residue and the processing residue (Table 6, Table 7).

4.3.1.2. Growing private investors. At this time, 5357 biogas plants of different capacities are operational in different areas of the country [62]. PCRET has developed various biogas plants according to the local environment. Amjid et al. [65] has presented fixed dome and moveable dome biogas plants and estimated the biogas potential in Pakistan. This could be highly accepted by the rural inhabitants as a cheaper and environment-friendly source of energy. Currently, 5 grid connected bagasse based power plants of cumulative capacity 160.1 MW are operational (Table 8) while 27 intended biomass power projects of cumulative capacity 974 MW are under different stages of project development (Table 9).

4.3.1.3. Environment-friendly. Though the emissions from bioenergy sources are less than the fossil fuel-based electricity generation, it is much larger than the other RE resources. Amponsah et al. [51] estimated the GHG emissions from dedicated biomass and waste to energy were 14–650 gCO_2-eq/kWh and 97–1000 gCO_2-eq/kWh respectively (Fig. 7).

4.3.2. Weaknesses

4.3.2.1. Inadequate handling of biomass. All the biomass energy sources as stated above are improperly collected, handled and transported from the fields to the point of use [67]. Lack of the modern methods of biomass collection and handling like briquetting and palletizing are the wastage of exploitable energy potential. The rural residents are the 62% of the total population in the country who meet their primary energy demands by burning the animal dung and the crop residues for space heating and cooking purposes [52,68]. The methods of conversion of biomass into useful energy are traditional and inefficient causing indoor air pollution and the wastage of energy [68]. In view of this, technical methods and machinery of collecting and managing biomass must be developed, along with that modern efficient cooking stoves need to be used in villages.

Table 8
Operational bagasse based project [12,66].

Sr. No.	Company	Capacity (MW)
1	JDW Sugar Mills (Unit-II), RYK	26.35
2	JDW Sugar Mills (Unit-III), Ghotiki	26.35
3	RYK Mills Limited, Rahim Yar Khan	30
4	Chiniot Power Ltd., Chiniot	62.4
5	Hamza Sugar Mills Ltd. RYK	15
Total		**160.1**

4.3.2.2. Ignorance of the energy crops. In Pakistan, almost all the farmers are ignorant of the energy crops like miscanthus, sorghum, switchgrass, jatropha, camelina, carinata, and arundo. These energy crops are short rotation energy crops, nonwoody crops, and grasses. Allocation of land and cultivation of energy crops over there would not only increase the quality biomass production but also increase the energy content of the biomass.

4.3.3. Opportunities

4.3.3.1. Utilization of the waste biomass. Though the bioenergy in Pakistan has widely been exploited, still there are a lot of opportunities that need to be availed. If the modern cultivation, irrigation and harvesting techniques are adopted, most of the biomass that otherwise is wasted could be used as a source of energy. The industry survey of the ESMAP regarding the biomass mapping in Pakistan surveyed 12 landfills in Pakistan and estimated that their compiled Municipal Solid Waste (MSW) was 29 million tons per day out of which unutilized 27 million tons can support anaerobic digester based power plant of 370 MW cumulative installed capacity [64]. Their industrial survey also estimated that the cumulative production of 3 surveyed dairy farms was 100 tons per day that could support a digester-based power plant of cumulative capacity of 0.4 MW.

4.3.3.2. Electrification of rural areas. About 62% of the population

Table 6
Annual theoretical potential of crop processing residue in Pakistan [65].

Residue type	Annual residue (Million tons)	Energy contents (GWh of thermal)
Bagasse	19.6	40,720
Rice Husk	3.3	12,566
Maize cob	1.4	6481
Maize husk	0.93	3018
Total	**25.2**	**62,785**

Table 7
Annual theoretical and technical potential of crop harvesting residue in Pakistan [64].

Residue type	Theoretical potential		Technical potential	
	Annual residue (Million tons)	Energy contents (GWh of thermal)	Annual residue (Million tons)	Energy contents (GWh of thermal)
Cotton stalks	49.4	206,020	6.0	25,073
Wheat straw	34.6	138,325	6.5	25,952
Rice straw	16.7	58,138	8.3	28,848
Sugarcane trash	7.8	29,835	3.5	13,397
Maize stalk	5.3	24,124	0.8	3619
Total	**113.8**	**456,442**	**25.1**	**96,889**

Table 9
Intended Bioenergy based power projects at different stages of development [66].

Sr. No.	Company	Capacity (MW)	Location
1	Layyah Sugar Mills	41	Layyah
2	Almoiz Industries Ltd.	36	Mianwali
3	Chanar Energy Limited	22	Faisalabad
4	Shahtaj Sugar Mills Ltd.	32	Mandi Bahudin
5	Etihad Power Generation Ltd.	74.4	Rahim Yar Khan
6	Hunza Power Pvt. Ltd.	49.8	Jhang
7	Bahawalpur Energy Ltd.	31.2	Bahawalpur
8	Indus Energy Limited.	31	Rajanpur
9	Ittefaq Power Pvt. Ltd.	31.2	Bahawalpur
10	Kashmir Power Pvt Ltd.	40	Jhang
11	Alliance Sugar Mills Ltd.	30	Ghotki
12	Safina Sugar Mills Ltd.	20	Chiniot
13	RYK Energy Limited.	25	Rahim Yar Khan
14	Sheikhoo Power Ltd.	30	Muzaffargarh
15	Hamza Sugar Mill Ltd (Unit-II)	30	Rahim Yar Khan
16	Mirpurkhas Energy Ltd.	26	Mirpurkhas
17	Faran Power Ltd.	26.5	Tando Muhammad Khan
18	Mehran Energy Ltd.	26.5	Tando Allah Yar
19	Two Star Industries Pvt Ltd.	49.8	Toba Tek Singh
20	Alman Seyyam Pvt. Ltd.	34.5	D.I.Khan
21	Habib Sugar Mills Ltd.	26.5	Shaheed Benzirabad
22	Sadiqabad Power Pvt Ltd.	45	Rahim Yar Khan
23	Gotki Power Pvt Ltd.	45	Ghotki
24	TAY Powergen Company Pvt Ltd	30	Tando Allahyar
25	Al-Mughnee Industries Pvt.	40	D.I.Khan
26	Darya Khan Power Generation Pvt Ltd	40	Bhakkar
27	Ranipur Energy Pvt. Ltd	60	Khairpur
Total		**913.4**	

lives in rural areas mostly joining the profession of farmers and dealing in livestock [68]. So far, only 55% of the villages of Pakistan have a grid connection for electricity [69]. Availability of biomass locally in villages is an opportunity to electrify these far-off villages. Biogas production from the biomass is another opportunity to generate biogas and use it for heating and cooking purposes. The by-product of the biogas plant is an important source of fertilizer that could be used in fields.

4.3.4. Threats

4.3.4.1. Policy against deforestation. Only 5.2% of the land of Pakistan is under forest. The deforestation rate is higher than the forestation. Most of the forests are in mountainous ranges that are a hill station for the tourists. Pakistan is adopting a serious policy against the forest lumber harvesting. Under national forest policy 2015, a timber regulatory authority has been formed to regulate the inter-province movement of timbers [70].

4.3.4.2. Sourcing threats. Sourcing of biomass in the required quantity is a major risk to the biomass projects. In bagasse cogeneration and rice mills' power projects, this risk becomes negligible as the requirement is made from the internal operation of the mills. However, for other biomass projects risk becomes high because their operation completely depends upon outside sourcing of biomass. For those biomass sources that are seasonally available, owners manage to buy all the source at the time of crop harvesting and store for the whole year. Owners may face the price escalation problem at that time.

4.3.4.3. Lack of locally developed technology. Biomass combustion technologies for wood chips, stalks, paddy husk, and other crop residues are matured in the world. In Pakistan, direct incineration of the biomass is the dominant technology. By adopting anaerobic digestion for biogas production can increase the conversion efficiency by 60% [71]. Table 10 gives the SWOT analysis summary of the bioenergy in Pakistan.

4.4. Hydro power

4.4.1. Strengths

4.4.1.1. Hydropower potential. Huge hydropower potential is the best asset of the RE sector of Pakistan. According to an estimation, Pakistan has almost 100 GW hydropower potential [8] and only 7.116 GW has been exploited that is 28.67% of the total energy mix [12]. WAPDA has set a target to increase it to 16 GW till 2025. By cost, hydel power is the best option to eradicate the demand-supply gap and for the sustainable development of the RE sector. Asif [71] declared the hydro-electricity to be the least cost source of electricity.

4.4.1.2. Well established technology. History of hydropower in Pakistan starts from 1925 with a run of canal project of 1.1 MW at Renala. Mega hydropower projects like Mangla and Terbela in Pakistan were commissioned in 1967 and 1977 respectively. In short, Pakistan has well experienced hydro constructors and plant operators. Currently, the share of hydro in the national energy mix is 29%. Major operational and under construction hydropower projects are shown in Fig. 6.

4.4.2. Weaknesses

4.4.2.1. Huge capital investment and time dilation. The major hurdles in the way of hydropower project development are the huge capital investment and the long time required for the completion of the project. Terbela dam was constructed in 8 years, Mangla dam in 5 years whereas, Ghazi Brotha dam took 10 years to achieve the COD. Neelam Jehlum was commenced in 2008 which is still under construction and the delay in the completion of the project has risen the cost from PKR 84 bln to PKR 500 bln [72].

4.4.2.2. Degradation of the reservoir. Another weakness of the hydropower is the reduction in live storage capacity of the dams with the increase in sediments. Mega hydropower projects of Pakistan Mangla, Terbela and Chashma have passed almost 50 years of their

Table 10
SWOT analysis of the bioenergy in Pakistan.

Strengths 1) A huge agricultural potential. 2) Locally available biomass. 3) Successful testing of locally developed biogas technologies. 4) Environment-friendly.	**Weaknesses** 1) Inadequate handling of biomass. 2) Lack of trained operators. 3) Farmers' ignorance of energy crops. 4) Inefficient boilers and furnaces. 5) Heterogeneity problem of biomass.
Opportunities 1) Utilization of waste biomass. 2) Electrification of rural areas. 3) Biogas availability in rural areas. 4) Availability of slurry fertilizer.	**Threats** 1) The policy against forest lumber harvesting. 2) Sourcing and unpredictable price fluctuations of biomass. 3) Lack of locally developed technology.
Recommendations 1) The government should introduce briquetting and palletizing machines. 2) Farmers must be briefed on energy crops. 3) Guaranteed supply of biomass. 4) Assured prices of biomass. 5) One window facility for investors.	

life and have reduced 20% their live storage capacity of water [71]. To maintain the storage capacity of the dam, regular rehabilitation is always required that also require extra time and cost.

4.4.3. Opportunities

4.4.3.1. Unexploited potential. Despite harnessing a lot of hydropower potential, there are still various opportunities that could be helpful in the sustainable development of the hydropower sector of Pakistan. Pakistan still has 93% hydro potential untapped that if properly exploited could be the foundation of an economic boost in Pakistan [73].

4.4.3.2. Micro-hydropower potential. Micro-hydro concept is another opportunity in this regard that could be exploited to electrify the off-grid local communities. Pakistan has 3100 MW out of which 9 micro/small hydro projects of cumulative capacity 98.41 MW are operational [12]. The micro-hydro potential is mostly available on canal falls, natural falls and canal flow in Gilgit Baltistan, Punjab and Khyber Pakhtun Khawa (Table 11).

4.4.3.3. Flood risk management. Every year, an unavoidable flood hit the flood-prone areas of southern Punjab and the Sindh and damage farmers' properties and the crops [74]. A devastating flood struck Pakistan in 2010 affecting 18 million people with their livestock, property, business, homes, and infrastructure [75]. Since 1973, Pakistan has faced seven major floods affecting 40 million people in total. Ashraf et al. [76] declared the lack of water storage capacity a reason behind the severe floods in Pakistan. By constructing dams, flood risk can be minimized in return wastage water would be available for electricity generation and irrigation purposes.

4.4.3.4. Capacity enhancement of the existing dams. Constructing new dams requires a lot of time and needs huge capital investment. It is better to enhance the capacity of already existing dams by extending the electricity generation capacity of the plants. Currently, the extension is being done only on Terbela dam whereas every large dam has the extension possibility of the power generation capacity. This opportunity can be capitalized by a minor investment resulting in a major increment in generation capacity.

4.4.4. Threats

4.4.4.1. Environmental hazards. Hydropower is considered totally clean and green energy. But, sometimes because of the negligence during site selection of the dam, it becomes totally unfriendly to the environment as it causes the extinction of various fish species and migration of other inhabitants. Building fish ladders/fish-ways arrange a bypass way for voyaging fish so that they can pass through a dam that's obstructive the path.

4.4.4.2. Political instability. Hydropower, being a long-term project, is always vulnerable to political instability. Existing government starts a hydropower project, the next government puts this project on the low priority list that causes an undue delay in the completion of the project. The institutional framework for the renewable energy sector must be strong enough to start a project and complete it without any external or internal political influence. Summary of the SWOT analysis of hydro energy in Pakistan is detailed in Table 12.

4.5. Geothermal energy

4.5.1. Strength

4.5.1.1. Resource potential. The resource potential of geothermal energy in the country is the biggest strength of the renewable energy sector. Geothermal energy in Pakistan is available in the form of mud volcanos, geysers, and hot springs [77]. Geothermal

Table 11
Micro/small hydropower potential in Pakistan [12].

Sr. No.	Area	No. of potential sites	Potential range (MW)	Total potential (MW)	Remarks
1	Kheber Pakhtun Khawa (KPK)	125	0.2 to 32	750	Natural falls/flows
2	Punjab	300	0.2 to 40	560	Canals
3	Gilgit Baltistan	200	0.1 to 38	1300	Natural falls
4	Sindh	150	5 to 40	120	Canal falls
5	Azad Jamu & Kashmir	40	0.2 to 40	280	Natural falls
	Total			**3100**	

Table 12
SWOT analysis of the hydropower in Pakistan.

Strengths	**Weaknesses**
1) Huge potential 2) 28.67% share in the energy mix. 3) Lowest cost of electricity. 4) Reduction in GHG emissions. 5) Well established technology. 6) Availability of experienced staff.	1) Huge capital investment 2) The longtime requirement in construction. 3) Degradation of the existing dams and hydropower plants by sedimentation.
Opportunities	**Threats**
1) Mini and micro-hydro potential. 2) Unexploited potential. 3) Flood risk management. 4) Adding capacity to existing dams.	1) Demolition of fish and wildlife habitat. 2) Political instability.
Recommendations	
1) Construction of fish ladder. 2) Generalization of legislation. 3) Promote run-off canal and micro-hydro. 4) Removal of mud regularly.	

potential in Pakistan is abundantly available in mud volcanos and hot springs. Karachi, Hyderabad, Northern areas and Chagai area are enriched in geothermal energy. Chemical and physical properties of geothermal reserves at Karachi, Gilgit & Hunza, Northern areas, and Chagai volcanic arc are detailed in Table 13, Table 14, Table 15, and Table 16 respectively.

4.5.1.2. Environment friendly-low emissions. Geothermal energy is another environment-friendly source of energy generating only 75–80 g CO_2-eq/kWh as shown in Fig. 7. Data of CO_2 emissions taken from Energy Information Administration (EIA) and Environmental Protection Agency (EPA) highlights the environmental feature of the geothermal power plant as compared to other competitors. Coal-fired power plants produce CO_2 emissions with an average rate of 888 g CO_2 -eq/kWh. Whereas the average rate of emissions for natural gas power plants is 499 g CO_2 -eq/kWh. On the contrary, geothermal plants are more environment-friendly with an average rate of 78 g CO_2 -eq/kWh [51]. Currently, geothermal power plants use binary technology, i.e., produce zero or near zero emissions [80] (see Table 17).

Geothermal Energy Association (GEA) estimated that 300 MW power from the geothermal system can save 4.5 million barrels of oil (enough to feed 100,000 cars) and avoid emissions of 2.25 million ton of CO_2 annually [80].

4.5.2. Weaknesses

4.5.2.1. Potential emissions. Sediments of different metals and hazardous gases under the earth surface may migrate to the earth surface, causing serious problems in the atmosphere. Geothermal projects may result in producing some gases that may trigger environment and health risks. H_2S gas as an example can be a serious threat to health if produced in large quantities. According to the WHO, the lowest observed adverse effect level for H_2S is 15 mg/m^3 that may cause eye irritation [84]. However, Low level of H_2S may result in diseases related to nervous, cardiovascular and respiratory systems. Workers may subject to risk as H_2S can accumulate in containers, closed or semi-closed areas as it settles in low lying areas because it is heavier than air [85]. Some traces of hydrogen, ammonia, radon, methane, hydrogen, nitrogen, boron, mercury and arsenic can be found in emissions; however, they are in very low concentration. Release of hot water in the environment during operation poses another serious implication. High-temperature geothermal plants most of the times contain Aluminum, mercury, arsenic, and lead that can cause health issues. As an example, due to the Wairakei power plant built in the late 1950s, the level of arsenic increased to more than double ever since. Hence, a high level of water treatment would be needed.

Table 13
Properties of hot spring at Karachi [78].

Location	Properties of hot water	Temperature (^{0}C)	Remarks
Karsaz	• Colorless • H_2S smell	39.0	Use for bathing
Mangopir	• Colorless • odorless	50.3	Use for bathing

Table 14
Reservoir temperature of Hunza and Gilgat [79].

Location	Reservoir Temperature (^{0}C)
Chilas	20
Budelas	39–40
Jaglot	10–65
Hakuchar	49–50
Murtazabad	26–91

4.5.2.2. Poor returns. Perception of poor return is another major problem associated with an investment in geothermal systems. High development cost, immature technology and uncertain behavior over returns are the main barriers to its progress. It is a relatively newer industry with little to no investors and low profits.

4.5.3. Opportunities

4.5.3.1. The potential use of geothermal heat. Geothermal energy can be used directly or indirectly. Indirect usage of geothermal energy is less efficient due to which cascading and closed loop usage is strongly recommended. As an example, geothermal based dry steam plants, flash steam plants, and binary cycle plants are employed [86]. Direct use of geothermal energy is significantly efficient. It can be used directly in a variety of ways including, greenhouse heating, home spaces, dying, industrial space heating, food drying, efficiency enhancement of sewage treatment plants, laundering and aquaculture ponds [87]. Direct use of geothermal is the most popular and oldest as it has been used by 82 countries around the globe for decades [88].

4.5.3.2. Market niche available. Energy security and reliability with their effects on economic security are integrated. Geothermal energy does not depend upon climate hence can provide energy more constantly than other renewable resources. Geothermal has a great

Table 15
Hot spring properties in Northern areas of Pakistan [77].

Location /Hot spring no.	Reservoir temperature (^{0}C)	Properties of hot water
Budelas		
1	46	colorless H_2S Smell Salty taste
2	36	H_2S Smell colorless
3	91	H_2S Smell colorless
Sassi		
1	54	odorless colorless $CaCo_3$ deposition
Murtazabad		
1	42.3	odorless colorless tasteless
2	36.9	odorless colorless $CaCo_3$ deposition
3	30.0	H_2S Smell colorless
Tatta Pani		
1	83	H_2S Smell salty taste colorless
2	65.5	Same as above
3	78	Same as above
4	57	Same as above
Mashkin		
1	57	H_2S Smell colorless
Chu Tran		
1	43.9	odorless colorless

Table 16
Hot spring properties in Chagai Volcanic Arc [78].

Location/ Hot spring no.	Reservoir temperature (^{0}C)	Properties of hot water
Koh e sultan volcanoes		
1	29.5	Odourless Pale brown Salty taste
2	32.2	same as above $CaCo_3$ deposition
3	32.0	same as above $CaCo_3$ deposition
4	26.9	same as above H_2S Smell colorless
5	25.5	Same as above
6	27.5	Odourless Pale brown Salty taste
Chicken Dik		
1	29.9	colorless H_2S Smell Salty taste

Table 17
GHG Geothermal emissions (gCO2-eq) [51].

Min.	Mean	Max.	Ref.
39	53	78	[81]
11	15	26	[82]
	41		[83]

tendency to lessen the trade deficit of any nation. Nevada's geothermal plants in the US save 3 million barrels of oil per year [89]. It will also benefit Pakistan as far as employment perspective is concerned. Geothermal projects will lead to direct and indirect employment. Direct jobs are related to construction and maintenance phase, whereas indirect jobs are meant to provide services, goods to firms involved in construction and maintenance process [90]. For at least four years, local job opportunities may arise due to drilling, exploration and initial setup installation phase. Also, full time and permanent workers will be required for operational [91].

4.5.4. Threats

4.5.4.1. Surface instability/seismicity. Geothermal power plants are always vulnerable to low magnitude events called microearthquakes. Prior to constructing a geothermal power plant, a careful study of the possible seismic impacts must be studied. In Switzerland January 1997, construction of a geothermal power plant caused an earthquake of 3.4 magnitudes on the seismic graph.

4.5.4.2. Efficient competitors. The main factor that impedes the use of geothermal energy is the low efficiency and less matured technology of generating power, primarily for medium and low-temperature resources. Oil, coal, natural gas, nuclear, hydro based power plants are more energy efficient as compared to geothermal, making it less competitive.

4.5.4.3. Insufficient planning, lack of interest and involvement. In Pakistan, there exist very few numbers of activities related to the exploration of geothermal resources. No effort has been undertaken to invest in technological and scientific research for exploration and development of geothermal energy. Researchers have tried to explore the geothermal potential of Pakistan [92]. However, comprehensive research, planning, and investment are required to make it happen. That will in return provide the best decision on geothermal development as well as socio-economic benefits. Whereas, the lack of proper understanding will lead towards the termination of exploitation and exploration of these resources. Summary of the SWOT analysis of the geothermal energy of Pakistan is given in Table 18.

5. Conclusion

Though the RE sector of Pakistan is in its initial phase of development, various RE projects like wind, solar, hydro, and biomass have successfully achieved their commercial operation date supplying electricity to the grid. Whereas, various are under different stages of project development. The potential of wind, solar, hydro and biomass energy sources is copiously available and technically exploitable in Pakistan. Owing to the institutional framework and operational RE projects, several local and foreign investors is increasing every year. The overall RE projects will mitigate the share of Pakistan in global GHG emissions. This paper enclosed various characteristics that must be talked to develop a supervisory context to inspire the development of RE. It presents recommendations not only for the new investors in RE but also gives a worksheet to the already existing RE projects to update the existing market situation.

From the exploration of the Strengths, Weaknesses, Opportunities, and Threats (Table 4, Table 5, Table 10, Table 12, and Table 18), a variety of arrangements could be inferred, some connecting up strengths and opportunities whereas others eliminating weaknesses and neutralizing the threats. Consequently, the recommendations in the national RE sector principally involve:

Table 18
SWOT analysis of the geothermal energy in Pakistan.

Strengths	**Weaknesses**
1) Resource potential	1) Potential emission
2) Environment-friendly	2) Poor returns
3) Skilled and experienced professionals	3) Immature technology
4) Emerging direct use sector	4) Lack of operation power projects
Opportunities	**Threats**
1) The potential use of geothermal heat	1) Surface instability/Seismicity
2) Market niche available	2) The high cost of electricity
3) Opportunity for the new off-grid market	3) Efficient competitors
	4) Lack of interest and development
	5) Inadequate funds
Recommendations	
1) Conducting seminars, conferences, and workshops for the socio-economic acceptance of the geothermal energy.	
2) Development of the licensing process for the private investors under AEDB.	

- The strategic policy for the RE must include the four key objectives: energy security, economic benefits, social equity, and environmental protection.
- Develop a RE policy managing the utilization of the potential strengths of the RE sources integrated with the GHG mitigation policy. Define the priority based future power project policy for clean and green energy sources. Strengthen the one window facility (AEDB) for the private investors in the RE sector.
- Diversify the national energy mix by developing policies that discourage the use of coal and imported oil for the electricity generation and encourage RE sources. Develop the RE sector by introducing some lucrative subsidies and incentives for the off-grid and on-grid power projects.
- Integration of the RE field to the national transmission grid is a big challenge as the wind corridors, solar parks, dams and most of the biomass-based power plants are far away from the electricity demanding areas. The government must promote rooftop solar installations and autonomous biomass power plants that would reduce the grid extension and the land acquisition cost.
- Develop RE projects in all over the country uniformly in those regions affluent in RE potential as the Baluchistan is affluent in solar and wind energy but unfortunately, not a single solar and wind-powered project is operational or in the pipeline.
- AEDB need to simplify the legislation and licensing policy for renewable energy projects.

Finally, the conducted SWOT analysis and policy recommendations on each renewable energy source with Pakistan perspective would provide a bottom line for the national renewable energy policy for sustainable development. Further, it would be helpful for the private investors, developers and, consumers to highlight the status and future success of each renewable energy project.

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